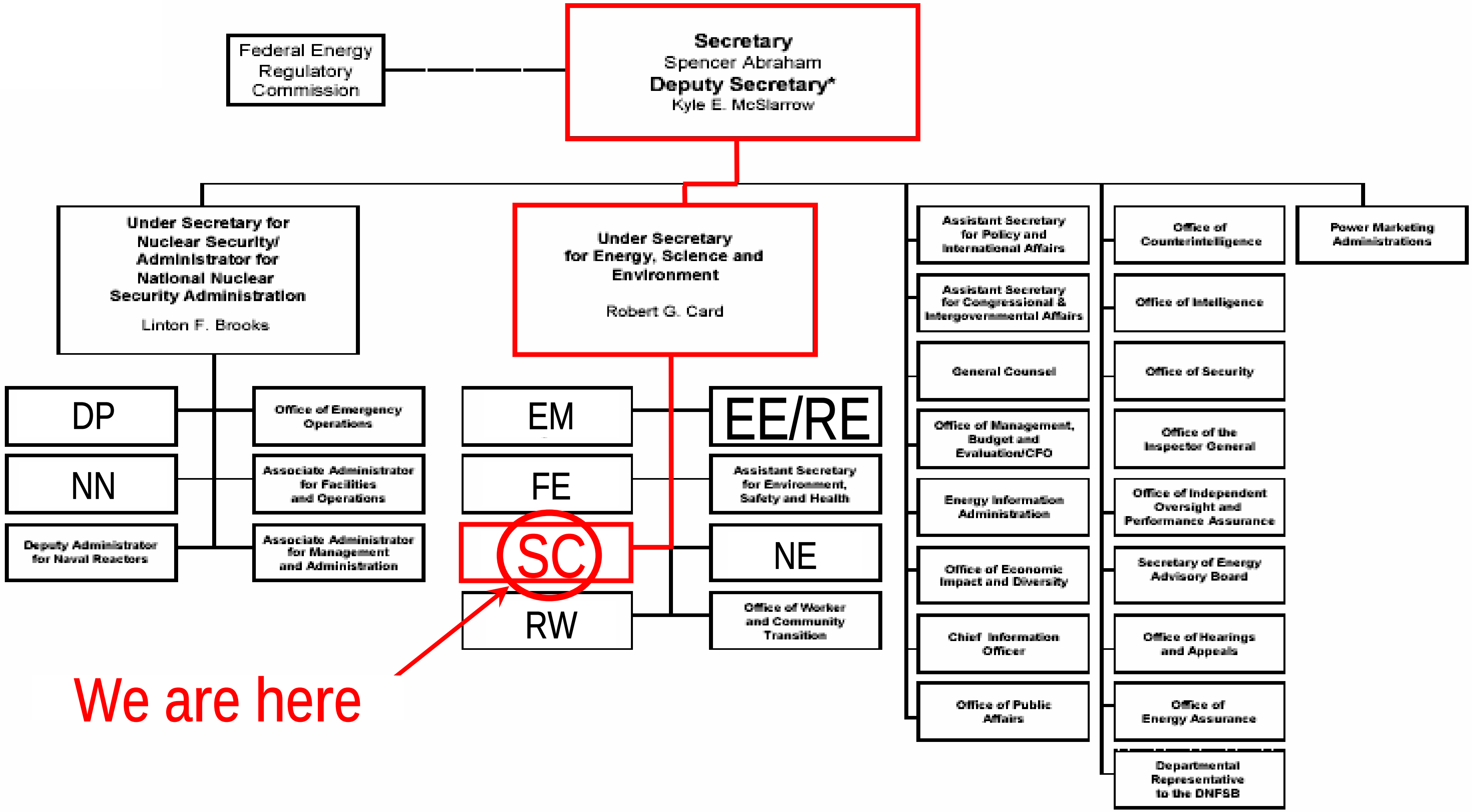
Solid State Lighting - Basic Research Synergies

Harriet Kung
Program Manager, Office of Basic Energy Sciences
Office of Science, U.S. Department of Energy

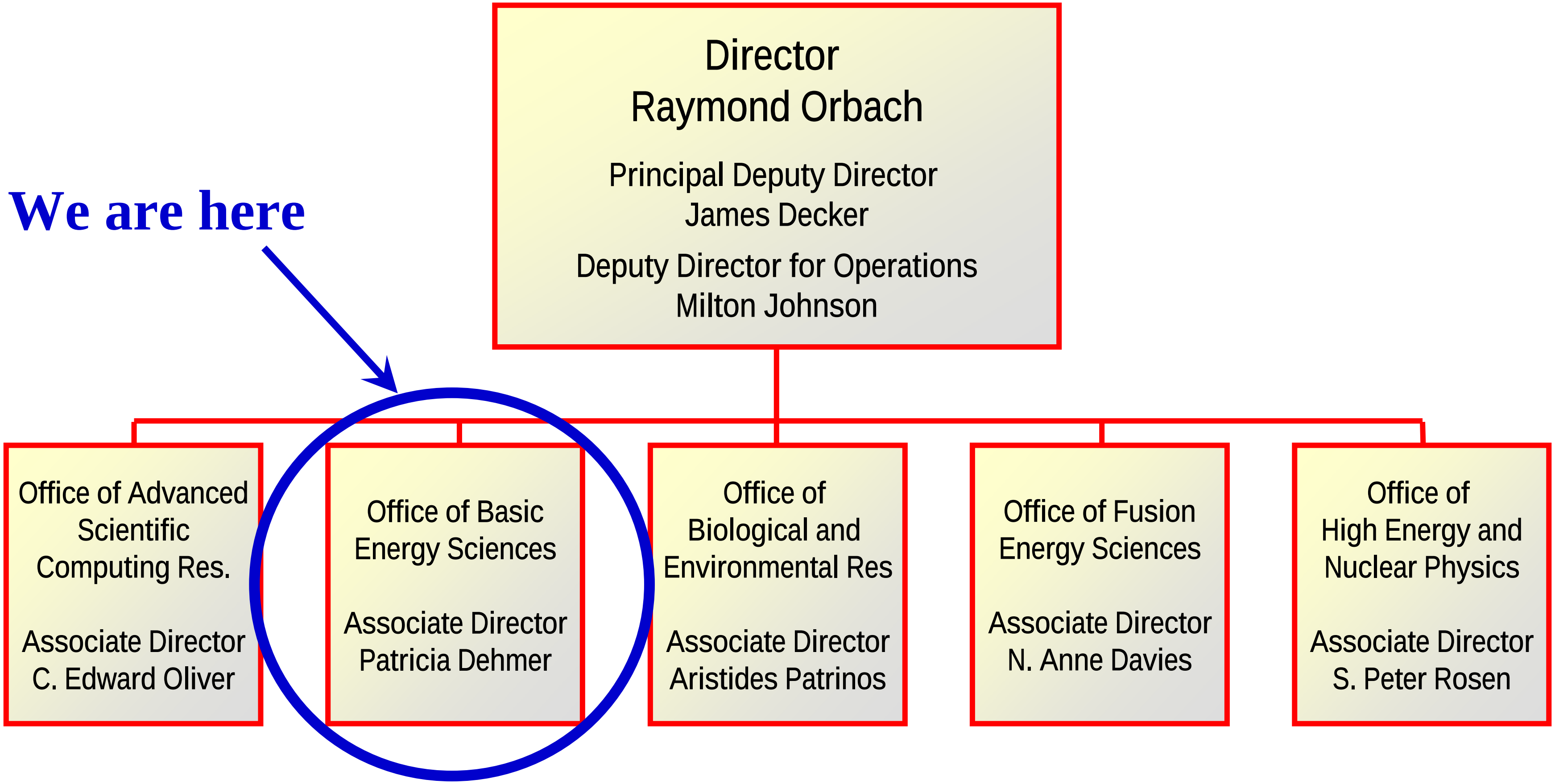
Solid State Lighting Program Planning Meeting

November 13, 2003
Doubletree Hotel, Crystal City, VA

Department of Energy Organization



DOE Office of Science



"… to foster and support fundamental research to expand the scientific foundations for new and improved, environmentally conscientious energy technologies"

"… to plan, construct, and operate major scientific user facilities for the Nation"

Office of Science - Basic Energy Sciences Program

- … is one of the Nation's largest sponsors of basic research;
- … supports research in more than 150 academic institutions and 13 DOE laboratories,
- … supports world-class scientific user facilities, and
- … is uniquely responsible in the Federal government for supporting fundamental research in materials sciences, chemistry, geosciences, and aspects of biosciences related to energy resources, production, conversion, efficiency, and use.

Basic Research Needs to Assure a Secure Energy Future


Basic Research Needs
To Assure
A Secure Energy Future

A Report from the
Basic Energy Sciences Advisory Committee

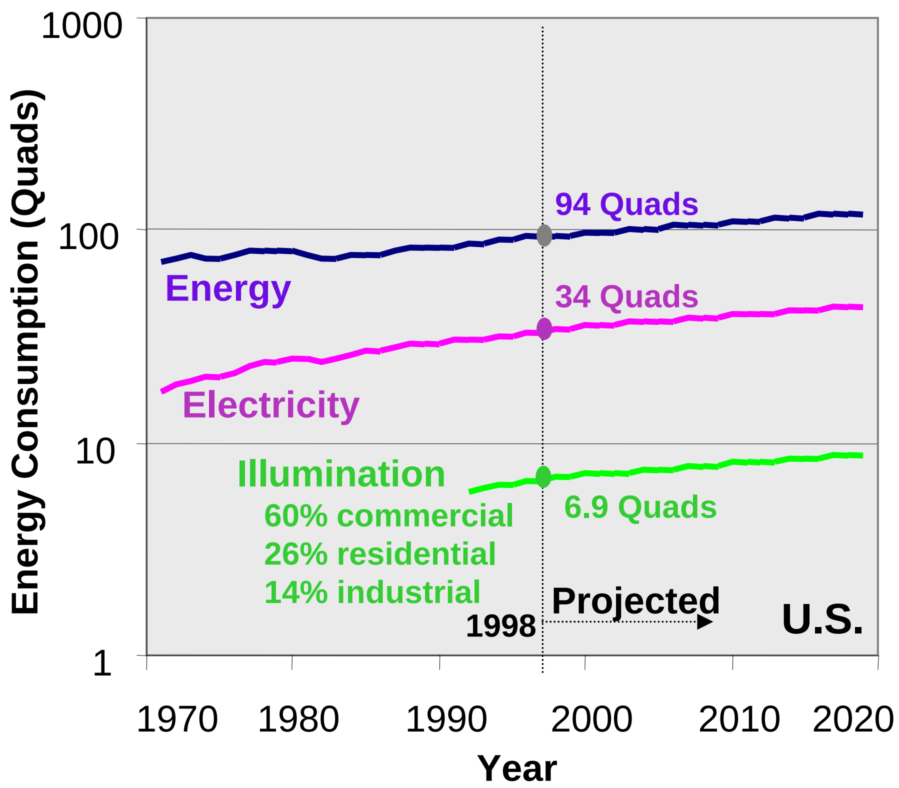
Basic Energy Sciences Advisory Committee Study

- A “Factual Document” summarizing the status of energy supply and use
- An Executive Summary
- A set of 37 Proposed Research Directions (PRDs)
- Supporting statements for each PRD in the form of a one-page Executive Summary and three pages of detailed information

Solid State Lighting Identified as a Proposed Research Direction

- Report web address: http://www.science.doe.gov/bes/BESAC/reports.html

Lighting is large fraction of energy consumption, and very low efficiency

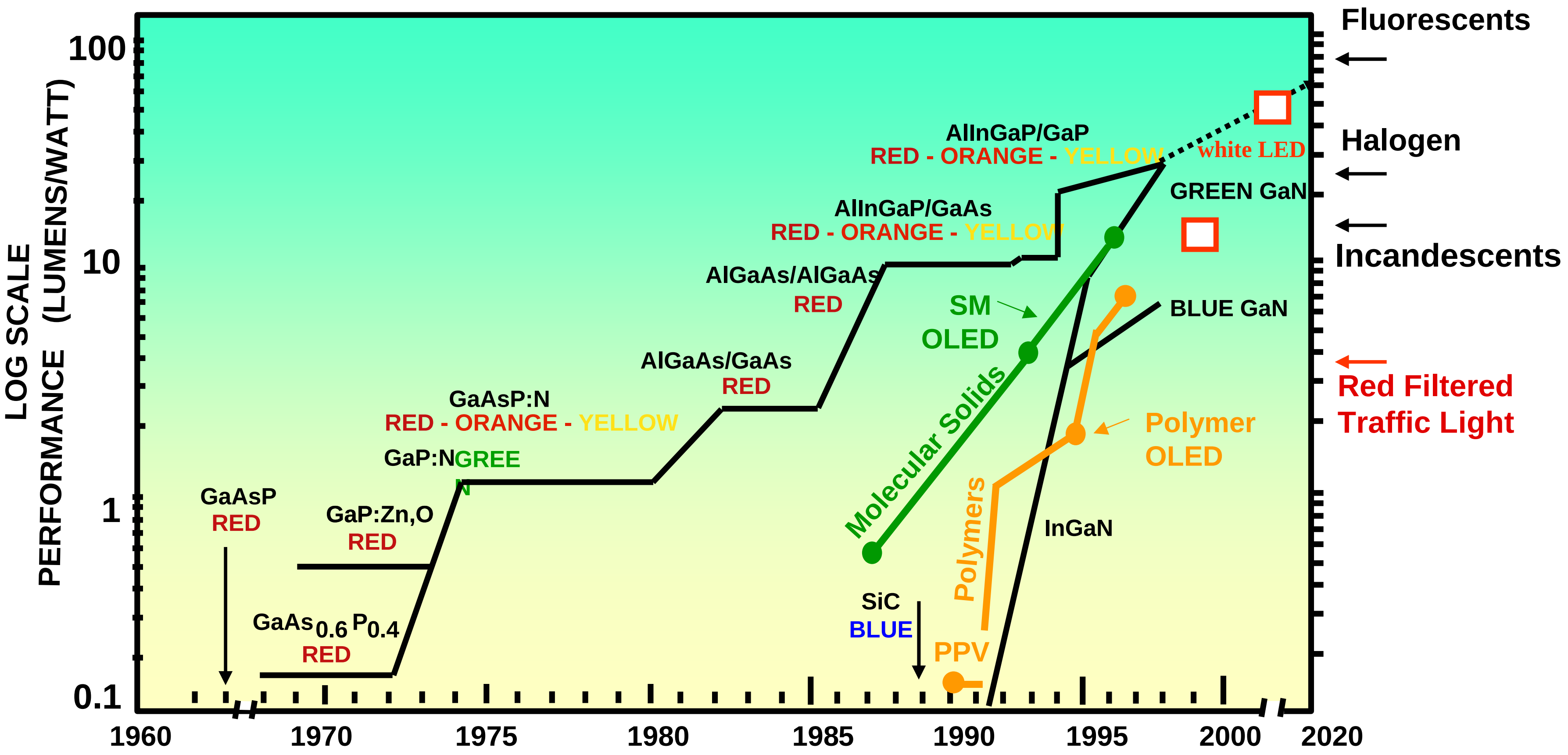


Efficiencies of energy technologies in buildings

Heating:	**70 -80%**
Electrical motors:	**85-95%**
Incandescent Lighting:	**5-6%**
Fluorescent Lighting:	**20-25%**

~20% of U.S electricity consumption is for general illumination

Increasing LEDs efficiency and Dropping Cost



RED: lumens/Watt has improved at 30X/decade, cost has decreased at 10X/decade.
BLUE: Recently blue Nitride-based LED materials have appeared.

BES-Supported Research Related to Solid-State Lighting

Goal: Obtain a fundamental understanding of basic physics and chemistry of new materials, both organic and inorganic, which could be used for solid-state lighting and related applications.

Major areas of current research:

1) Structures, properties and defect physics of wide bandgap semiconductors;

2) Coupled 1D quantum wires and self-assembled quantum dot arrays for nanoelectronic and nanophtotonic interactions;

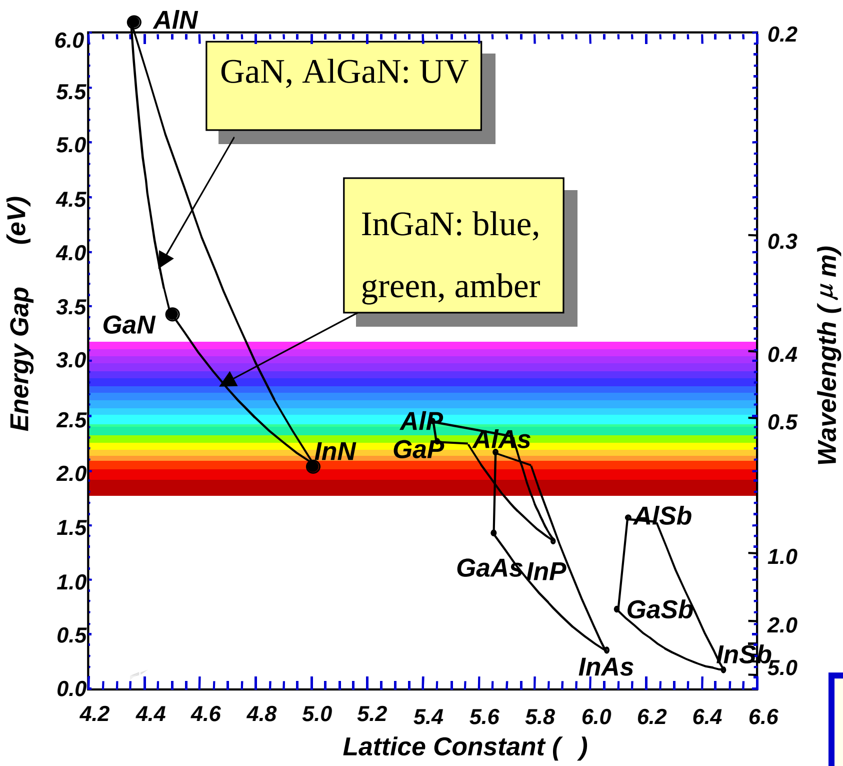
3) Theory and modeling of doping on electronic structures;

4) Electroluminescent organic materials and devices

Topics Identified by BESAC Energy Security Workshop:

Synthesis and Processing, Electronic Transport, Dislocations and Defects, Band-Structure, Impurity, Electron-Impurity Interactions, Radiative and Nonradiative Recombination Mechanisms, Nanostructures, Degradation Mechanisms.

AlGaInN Blue & UV LED Materials are Very New, Considerably Different from Other III-Vs, and Little Understood

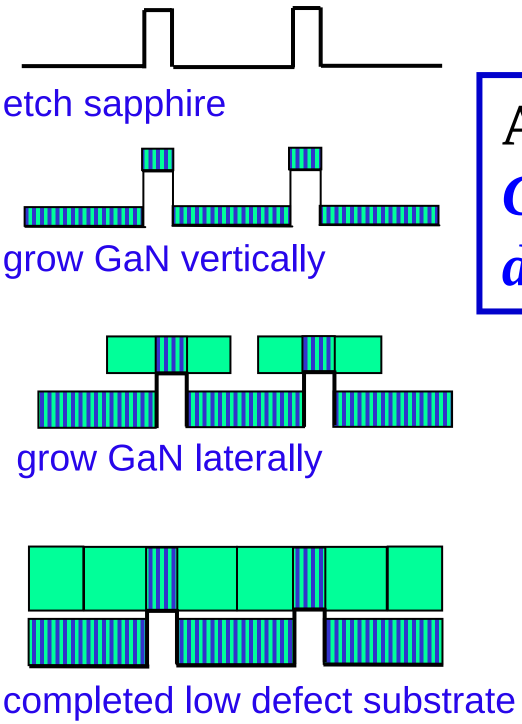


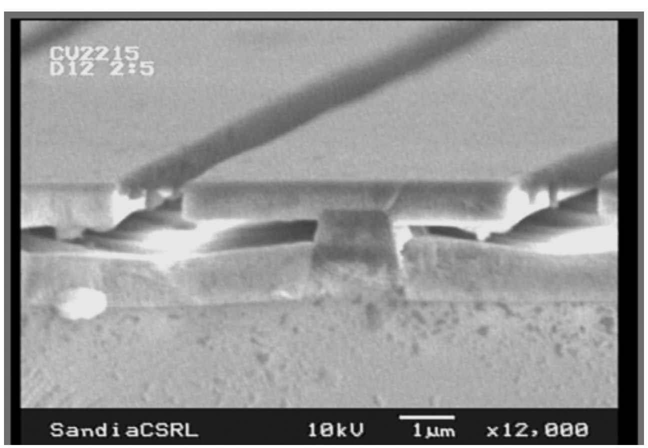
Nitride Materials Challenges:

- No lattice-matched substrate is known (dislocations form due to lattice mismatch)
- AlGaN not lattice-matched to GaN (dislocations and cracking)
- Mg p-type doping problematic (poor activation, high resistance)
- Growth process is poorly understood and difficult to control

Optical & Electrical Properties Dependent on Defect Concentrations

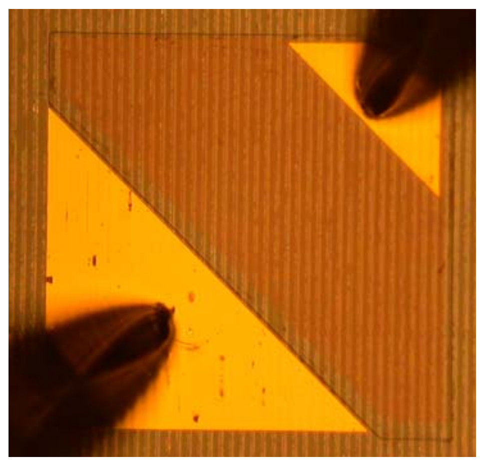
Cantilever Epitaxy Reduces Defect Density in GaN



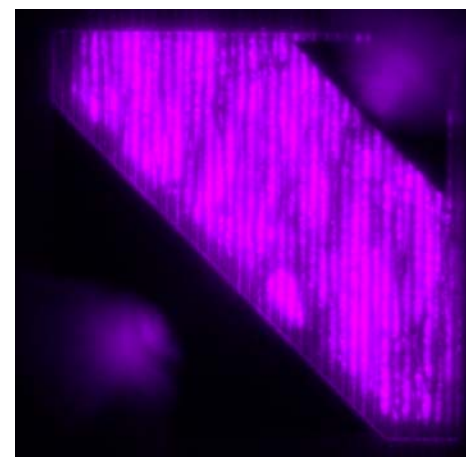


A major challenge - lack of a native GaN substrate
Growth on sapphire and SiC produces high defect density material with poor optical properties.

White-light Illumination



LED Electroluminescence

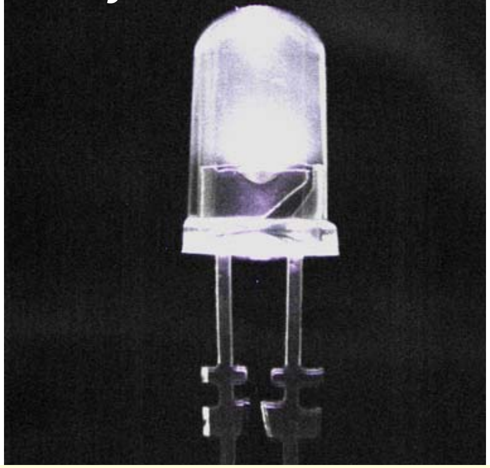


LEDs Grown on Cantilever Epitaxy Substrates Exhibit 15X Increase in Brightness

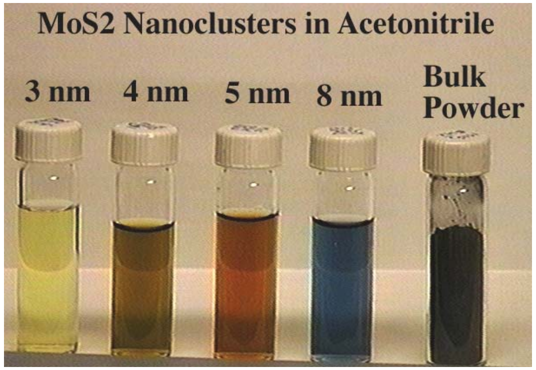
J. Simmons et al., SNL-NM

Nanocrystalline Quantum Dots May Provide Tunable "Phosphors" Superior to Nature's

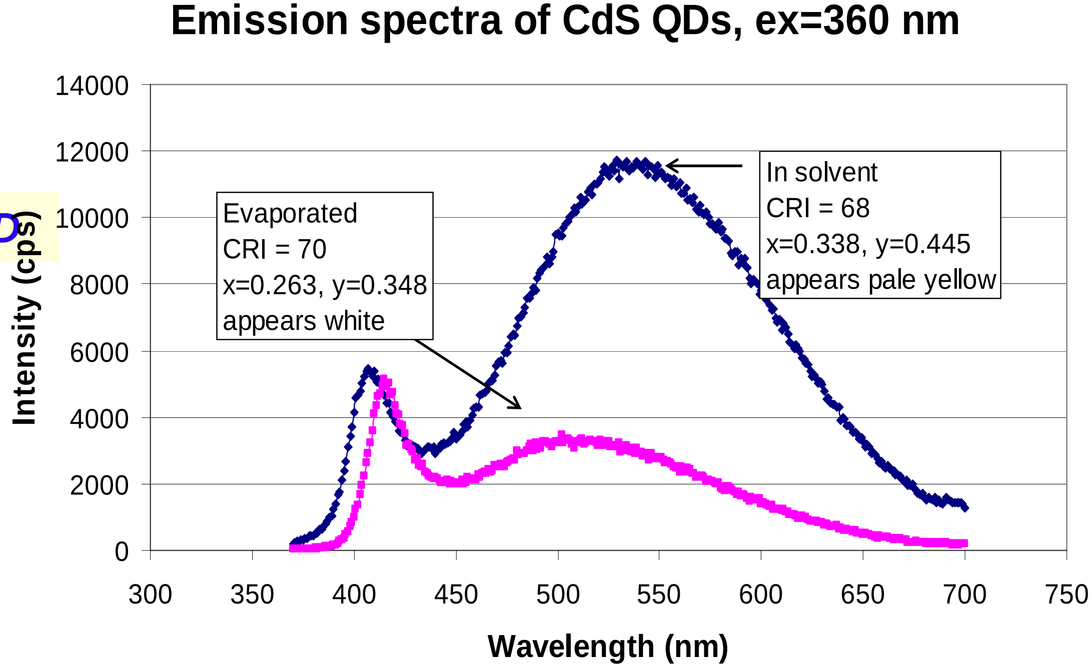
White-emitting CdS QDs in epoxy excited by 388 nm LED



World's 1st All-Quantum Dot LED



- **Optical properties of quantum dots can be tuned by**
  - **Size**
  - **Surface treatment**
- **First direct synthesis of white QD mixture**
- **World record quantum efficiency of 60-70%**



J. Simmons et al., SNL-NM

Organic LEDs

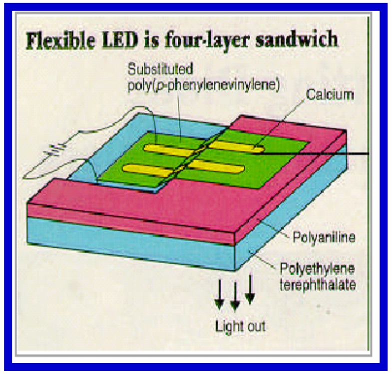
Major Application Drivers

Large area white light emissions

Large area and low cost electronics

Novel functionalities- PVs, FETs, sensors

Organic Spintronics

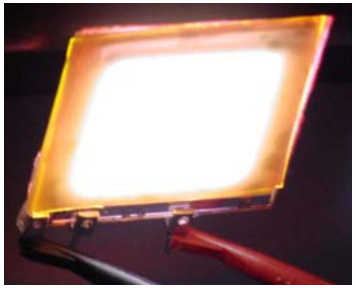


Key Conceptual Questions

- **What is so special about the few “magic” materials? (Alq3, Polyfluorene)**
- **What are the roles of material interfaces?**
- **What controls the singlet -triplet exciton formation ratio in conjugated materials?**
- **What are the degradation mechanisms?**
- **Why are the intrinsic limitations for making blue devices?**

DOE-BES/EERE Jointly Sponsored Workshop on Fundamental Research Needs in Organic Electronic Materials

Objective: To identify key scientific issues and research needs enabling the technological success of organic electronic materials



Date: May 23 - 25, 2003
Place: University of Utah, Salt Lake City, Utah
Co-Chairs: Alan Heeger, UC Santa Barbara
Valy Vardeny, University of Utah
~ 30 Invited Participants

Key Topics:

- Charge Injection
- Exciton Dynamics and Transport
- Spin Dynamics
- Charge/ Energy Transfer
- Electrical Transport
- Organic Heterostructures
- Optical Processes
- Organic Film Structure
- Theory (Quantum Chemistry & Condensed Matter Physics)

Summary of Key Scientific Issues

1. OLEDs

Carrier Injection (ohmic contacts), Spin Effects (singlets vs. triplets), Interfaces, Theory and Modeling, Light Extraction, Material Purity, and New Organic Semiconductors

2. Organic Transitors

Grain Boundary Effects, Defects, Injection into FETs, Crystallinity, Mobility, Reversed Sweeping and Cycling Stress Effects, Long-Time Relaxation Effects

3. Photovoltaic and Solar Cells

Charge Generation, Field Effects on Charge Separation, Carrier Mobilities, Polaronic Effect, Charge Collection Efficiency, Organic Semiconductor Bandgap Engineering

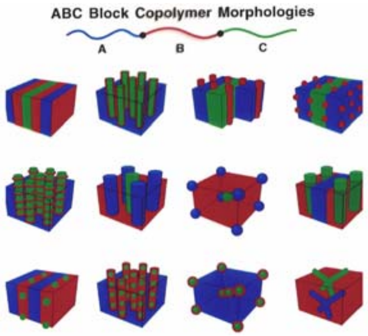
4. Organic Spintronics

Tunneling vs. Transport, Limit of Spin Diffusion Length, Magnetoresistance, New Electrode and Organic Materials, Interfaces, Temperature Dependence, Stability

Fundamental Research Needs in Organic Electronic Materials Workshop

Conclusions: Optimism and Opportunities

A. Heeger, UCSB



G. Bazan, UCSB

1. Materials

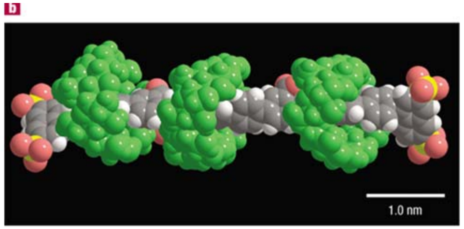
Structure and Purity

Do we have what we think we have???

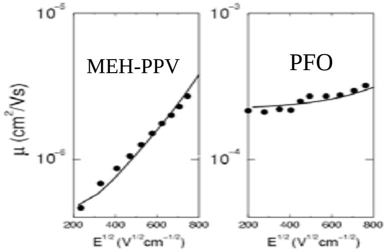
The wonders of chemistry-

Guided by quantum chemistry and intuition

Opportunity: Block copolymers, self assembly at the molecular level



Cacialli et al, Nature Materials | VOL 1 | NOVEMBER 2002, pg 160.



Mobilities Modeling
D. Smith, LANL

2. Theory and Modeling

Charge injection and transport

Electronic structure calculations

– DFT of aligned chains (“crystal”)

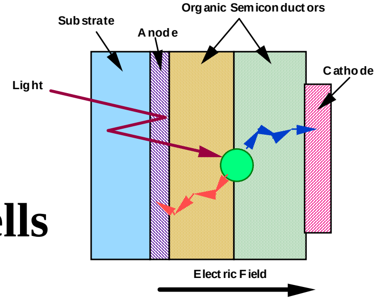
3. Device Physics

Organic FETs

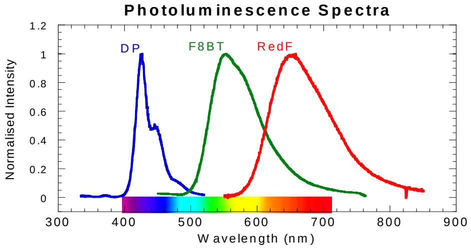
Organic spintronics

PVs/Electrochemical Cells

Spintronics

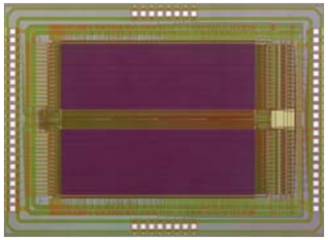


Organic PVs



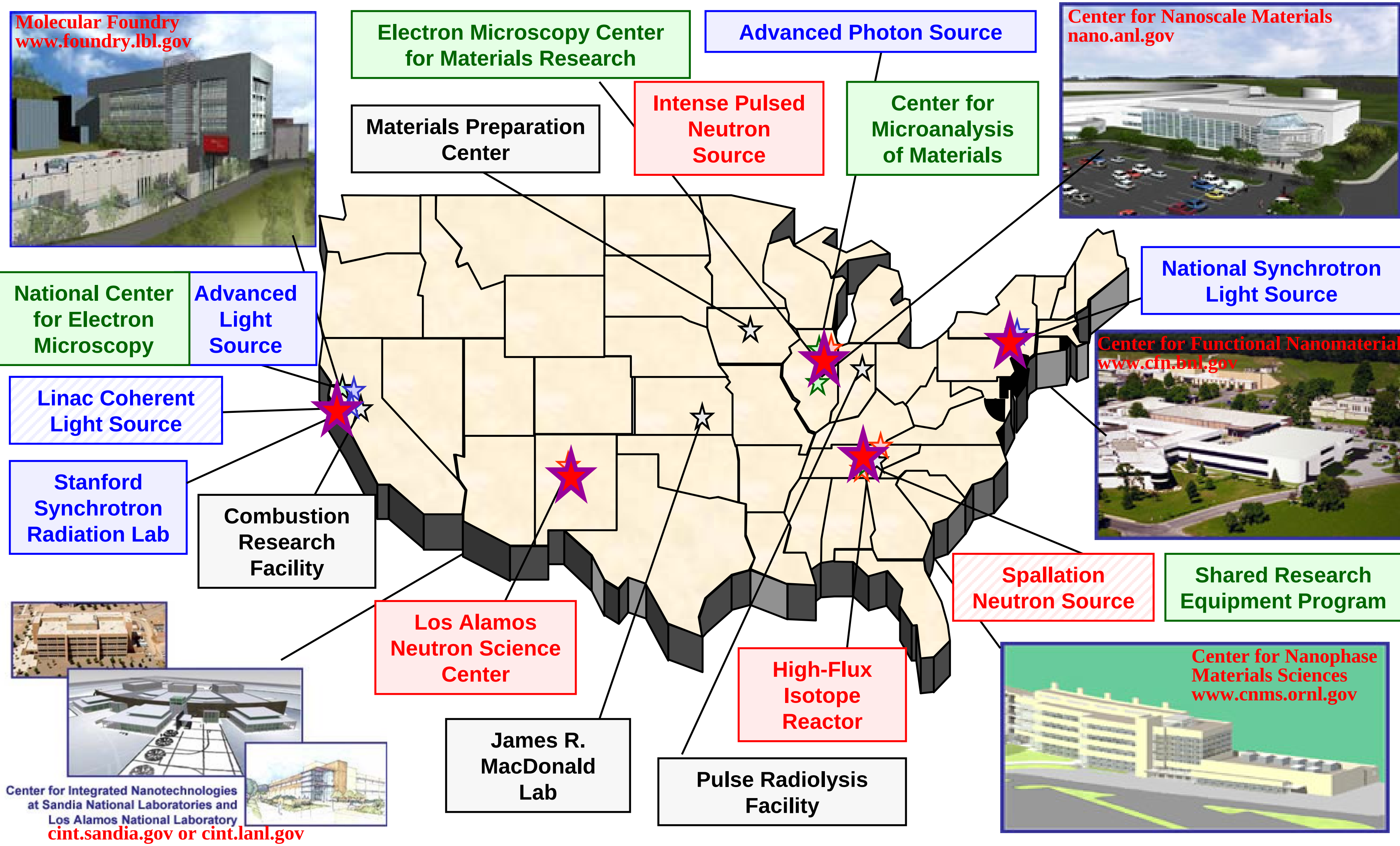
Polymer Lasers

Bradley, Imperial College London



1MB prototype chip shown by Motorola in June 2002

NSRCs (★) and the BES User Facilities



DOE Nanoscale Science Research Centers Overview

- **Research facilities for synthesis, processing, fabrication, analysis, and characterization of nanoscale materials**
- **Co-located with existing user facilities (synchrotron radiation light sources, neutron scattering facilities, other specialized facilities) to provide characterization and analysis capabilities**
- **Operated as user facilities; available to all researchers; access determined by peer review of proposals**
- **Provide specialized equipment and support staff not readily available to the research community**
- **Conceived with broad input from university and industry user communities to define equipment scope**
- **Initial user operations underway <u>now</u> (a jumpstart) - Four of the five centers have solicited proposals for collaboration; the fifth one will issue the solicitation by end of 2003**

Research Programs and Funding Opportunities

- **Core Research Program**
  http://www.science.doe.gov/bes (Office of Basic Energy Sciences)
  http://www.science.doe.gov/bes/dms/DMSE.htm (Division of Materials Sciences & Engineering)
  http://www.science.doe.gov/grants/ (sponsored research details)
  http://www.energy.gov/scitech/index.html (science and technology across the Dept. of Energy)

- **Major Research Facilities**
  http://www.sc.doe.gov/bes/BESfacilities.htm
  http://www.science.doe.gov/bes/User_Facilities/dsuf/DSUF.htm
  - BES Nanoscale Science Research Centers – the DOE "flagship" NNI activity
  - BES supports synchrotron, neutron, and electron scattering (and other) user facilities

- **SBIR/STTR** (http://sbir.er.doe.gov/sbir)
  - FY 2003 solicitation contained relevant technical topics, including:
    - Solid State Organic Light Emitting Diodes For General Lighting
    - Nanotechnology Applications in Industrial Chemistry
    - Nanomaterials for Energy Efficiency